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Estimation of Per Capita Loading and Treated Wastewater Quality Index in Sharkia Governorate, Egypt

Ahmed Aboulfotoh[1*], Ghada Heikal[1]

[1] Environmental Engineering Department, Faculty of Engineering, Zagazig University, El-Zakazik Rd, Shaibet an Nakareyah, Zagazig 2, Sharqia, 44519, Egypt

* Corresponding author's e-mail: aseaf_1@yahoo.com

ABSTRACT

Monthly reports (from June 2017 to May 2018) of twenty-one wastewater treatment plants in Sharkia were evaluated for the following parameters: temperature, pH, total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrate (NO_3), oil and grease (O&G) and Dissolved Oxygen (DO) values. The first aim of this study was to estimate the main wastewater per capita pollution generation per day (PCPL) and it was found that the 90th percentile PCPL for TSS, COD, BOD, NO_3 and O&G were equal to 57.42, 91.59, 59.13, 1.64 and 12.39 (g/capita/day) respectively. The second aim was to assess the performance of the WWTPs in the governorate, by calculating of the wastewater quality index (WWQI) of each plant and for the entire governorate, which shows that 2 WWTPs give a good performance, 9 WWTPs give a fair performance, 9 WWTPs give a marginal performance and 1 WWTP is in bad condition, the average performance all over the governorate is considered marginal. A simple empirical formula has been established to be used for calculation of the WWQI based on the tested parameters using the multiple linear regression and found to be very effective in predicting the WWQI for the WWTPs.

Keywords: domestic wastewater, evaluation, per capita loading, water quality, WWQI, WWTP.

INTRODUCTION

Water contamination is one of the foremost perilous dangers influencing the majority of world countries. The change in water quality altering the natural balance of waters is known as water pollution. The pollution of water is linked to industry, sewage, or agricultural drainage (Ramadan et al., 2017). The pollution from wastewater is currently the greatest threat to the sustainable use of surface and groundwater. Today, household, commercial, and industrial effluents as well as raw untreated sewage are often discharged into the surface freshwater sources. Moreover, in most developing countries, the untreated wastewaters from rural areas are often discharged directly into the waterways. The wastewater eventually percolates or is washed into the water bodies by rainstorms (Mahgoub, et al. 2015). Wastewater needs to be characterized before being handled to determine the compositions that are important for powerful design and operation of wastewater treatment plant (Abdallaa and Hammam, 2014). The amount of characteristic loading is one of the principal boundaries in the design of wastewater collection and treatment systems. The per capita loading of wastewater characteristics such as chemical oxygen demand, biological oxygen demand, nitrogen, phosphorus and solids have been considered as useful main functions in the design of wastewater collection systems and in the control of water resources pollution. The pollutants per capita values can be utilized to estimate the pollution loading of wastewater produced from a population, which is also very useful for estimating the equivalent population of an urban or industrial wastewater flow (Mesdaghinia et al. 2015).

The primary function of wastewater treatment plants (WWTP) is to protect the environment and human health from excessive overloading from pollutants of various types. Wastewater treatment plants are considered one of the major infrastructure assets (Vanier & Danylo, 2003). The degree of treatment provided to the wastewater will largely be based on the effluent standards prescribed by the regulatory agencies, when the treated effluent is to be discharged into a watercourse or land. If the effluent is to be reused, the quality of the effluent required to support such reuse will indicate the degree of treatment necessary (Naidoo and Olaniran 2014).

Water quality index (WQI) provides a single value that indicates the overall water quality under specified conditions of time and location depending on various water quality parameters. This concept of WQI is applied to wastewater and the quality of the wastewater may be determined based on the wastewater quality index. The wastewater quality index can be defined also as a single value, which reflects the overall wastewater quality related to its input constituent parameters (Praus, 2019). Developing the WWQI on the line of WQI is expected to be more practical in implementation and can become effective decision-making tool for authority (Khambete, Christian, 2014).

The first aim of this study was to estimate the main wastewater pollution generation per capita per day for the following parameters, total suspended solids, chemical oxygen demand, biochemical oxygen demand, nitrate, and oil and grease according to the recorded data of wastewater treatment plants in Sharkia. The second aim was to assess the performance of the WWTPs in the governorate, by calculating of the WWQI of each plant and for the entire governorate, then establishing an empirical formula for the calculation of the WWQI based on the tested parameters.

METHODS

Study area

The Sharkia governorate is located at latitude 30.7°N and 31.63°E longitudinal at an altitude of 10 m above the mean sea level (Fig. 1). The area of the Al-Sharkia Governorate is 4,911 km^2, equivalent to 1.07 million acres. It is the third governorate in population at the level of Republic after Cairo and Giza Governorates, with population of 7,192,355 capita at 2017. Water supply covers only 92.6% of the population by water

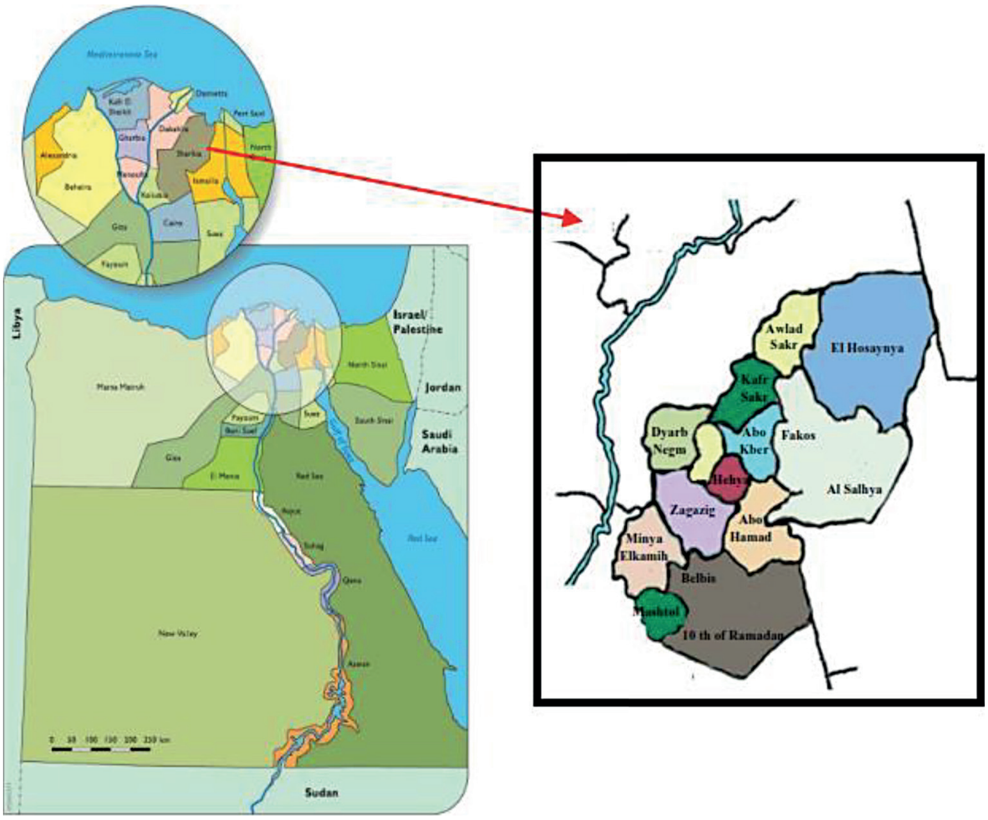

Figure 1. Sharkia governorate location (Eldeeb & Zelenakova, 2019)

treatment plants with capacity of 365 $M.m^3$/year, while the wastewater treatment capacity does not exceed 146 $M.m^3$/year. In developed communities and cities, the water use lies between 150 and 250 l/capita/day, with major cities in the United States at over 400 l/capita/day. Egypt has an average water consumption of 220 l/capita/day while Sharkia Governorate has an average water consumption of 150 l/capita/day (IWA 2014, CAPMATH 2017).

Physicochemical data

The data used in this study was obtained from monthly reports (June 2017 to May 2018) of twenty-one wastewater treatment plants in Sharkia. The reported data include the following parameters: temperature, pH, total dissolved solids, total suspended solids, chemical oxygen demand, biochemical oxygen demand, nitrate, oil and grease and Dissolved Oxygen (DO) values, all these parameters measured according to the standard methods for the examination of water and wastewater (APHA 1999). These data were collected by Sharkia Holding Company of Water and Wastewater management, the reported monthly value is the average of 4 measurements. The design capacity of Al Zagazig was 90,000 m^3/d, while the design capacity of the remaining 20 WWTPs ranged between 10,000 and 20,000 m^3/d.

Four (Abu Hamad, Al Qenayat, Al Halawat and Pordin) out of the 21 WWTPs use the Trickling filters (TF) attached biological growth systems wherein wastewater is applied to rock (gravel) media. The microorganisms growing on the TF media oxidize and synthesize organics in the wastewater. Insignificant quantities of nitrogen and phosphorus are removed through synthesis of biomass. Generally, trickling filters produce an effluent with BOD and TSS values ranging from 15–30 mg/l or that equivalent to secondary treatment (Metcalf & Eddy, 2013; Qaim, 2017; WEF, 1998).

The remaining 17 WWTPs use the activated sludge process, which is a two-step sequential process consisting of aeration basin for substrate utilization, followed by secondary clarifier for solids-liquid separation. Generally, in well-operated systems treating domestic wastewater at a solids retention time (SRT) of 4 days or longer, the effluent soluble BOD is <3mg/l and effluent TSS concentrations range from 5–15 mg/l (Metcalf & Eddy, 2013; Qaim, 2017; WEF, 1998).

Calculation of the Wastewater Quality Index

The Wastewater Quality Index was developed by the Canadian Council of Ministers of Environment (CCME, 2001) and based its development on the combination of three factors into one index. The detailed formulation of the WWQI comprises three factors as follows:

Scope (F_1) – the number of variables whose objectives are not met:

$$F_1 = 100 * \frac{Number\ of\ failed\ Variables}{Total\ No.of\ Variables} \tag{1}$$

Frequency (F_2) – the frequency with which the objectives are not met:

$$F_2 = 100 * \frac{Number\ of\ failed\ Tests}{Total\ No.of\ Tests} \tag{2}$$

Amplitude (F_3) – the amount by which the objectives are not met, and could be calculated in three steps:

1. The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is estimated as follows;

$$Excurions_i = \frac{Failed\ Test\ Values_i}{Ojective_i} - 1 \tag{3}$$

For the cases in which the test value must not exceed the objective:

$$Excurions_i = \frac{Ojective_i}{Failed\ Test\ Values_i} - 1 \tag{4}$$

2. The collective amount by which individual tests is out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse), is calculated as:

$$nse = \sum_{i=1}^{n} \frac{Excurions_i}{Number\ of\ tests} \tag{5}$$

3. F3 was thereafter calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100 as given in Equation

$$F_3 = \frac{nse}{0.01nse + 0.01} \tag{6}$$

The WWQI is determined using equation below:

$$WWQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{7}$$

Table 1. The grade of wastewater quality for corresponding values of WWQI (Praus, 2019)

WWQI	Wastewater quality
95–100	Excellent
80–94	Good
65–79	Fair
45–64	Marginal
0–44	Poor

The calculation produces a score value that ranges between 0 and 100. The higher the score, the better the quality of water. Table 1 shows the grade of wastewater quality for corresponding values of WWQI.

RESULTS AND DISCUSSION

Raw wastewater quality and per capita pollution load estimation

Table (2) shows the yearly average raw wastewater characteristics during the study period for each WWTP, and for the whole governorate. As presented in the table, there is no significant difference between the WWTP inlet characteristics, the monthly average values of temperature ranged between 22.5 and 26.57°C; the pH value ranged between 6.65 and 7.42, TDS ranged between 742.57 and 1432.67 mg/l, TSS ranged between 315.10 and 470.56 mg/l, COD ranged between 438.80 and 875.89 mg/l, BOD ranged between 304.78 and 584.89 mg/l, NO_3 ranged between 0.04 and 7.81 mg/l, and O&G ranged between 62.70 and 102 mg/l. These results comply with those of Mahgoub, et al. (2015) who studied the changes in microbiological, physical and chemical quality in 17 WWTPs in Sharkia during the year of 2012 and also with the results of Abd-El-Kader et al., (2020).

The wastewater strength of the governorate places between the medium and high strength wastewater with tendency for higher values (Metcalf & Eddy, 2013; Qaim, 2017; WEF, 1998). The table shows the 90th percentile concentrations

Table 2. Yearly average raw wastewater characteristics during the study period

WWTP	Temp (°C)	pH	TDS (mg/l)	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	NO3 (mg/l)	O&G (mg/l)
Abu Hamad	23.91	7.10	742.57	341.00	611.43	385.29	6.06	66.29
Abu Kabir	24.03	7.29	1102.00	326.10	529.50	315.20	7.81	63.10
Abu Metna	23.30	7.42	1055.33	317.33	477.22	304.78	4.71	69.33
Al Halawat	25.66	7.13	1001.55	375.73	610.55	390.73	4.04	70.45
Al Hussaniah	24.99	6.84	1119.60	315.10	508.60	346.80	4.01	65.00
Al Qenayat	25.01	7.27	974.06	343.88	542.12	330.88	6.95	65.71
Al Qurin	24.35	7.11	831.15	351.08	704.62	445.38	3.85	66.23
Al Rewad	23.20	7.23	1080.00	377.75	569.25	351.50	0.89	85.75
Al Robomaiah	24.34	7.05	807.20	338.70	438.80	316.40	5.05	62.70
Al Taibah	22.52	7.12	1108.30	331.00	526.90	316.50	3.72	75.10
Al Zagazig	25.38	7.42	1063.56	470.56	683.67	424.11	2.25	90.67
Anshas	25.21	7.26	955.71	341.07	552.71	353.07	4.56	67.57
Awlad Saqr	26.57	7.10	981.20	318.40	495.90	309.00	3.89	63.60
Fakous	24.20	7.11	914.38	339.25	559.88	357.44	4.28	69.56
Heheia	25.76	6.94	901.50	381.64	622.43	386.29	3.14	99.29
Kafr Saqr	24.71	7.15	900.73	321.27	528.18	345.64	4.47	65.82
Lebo	25.16	7.21	1164.73	346.91	550.09	342.73	3.55	67.82
Pordin	25.98	6.65	1120.50	382.20	703.50	457.50	0.04	86.70
Safor	23.03	7.11	1432.67	456.22	875.89	584.89	4.86	102.00
Shlshalmon	24.80	6.98	839.67	343.83	532.33	333.83	4.58	75.50
Sowod	24.93	7.13	1215.30	320.70	492.90	326.10	4.78	62.80
Governorate average	25.40	7.12	1003.66	352.34	575.33	366.36	4.31	72.83
Governorate 90th percental	30.52	7.628	1320	450	718.4	463.8	12.9	97.2
Low strength WW	ND	ND	374.00	130.00	339.00	133.00	0.00	51.00
Medium strength WW	ND	ND	560.00	195.00	508.00	200.00	0.00	76.00
High strength WW	ND	ND	1121.00	389.00	1016.00	400.00	0.00	153.00

which could be used for the purpose of design of the upcoming extensions/new WWTPs.

The per capita pollution load for TSS, COD, BOD, NO_3 and O&G could be calculated using the equation below:

$$PCPL_i = \frac{C_i * q}{1000} \quad (8)$$

where: $PCPL_i$= per capita pollution load for (i) parameter (g/capita/day); C_i= Concentration for (i) parameter (mg/l); q = per capita sewage flow rate = 0.85 * per capita water consumption= 127.5 (L/capita/day).

Using the 90th percentile concentration directed to PCPL for TSS, COD, BOD, NO_3 and O&G equal to 57.42, 91.59, 59.13, 1.64 and 12.39 (g/capita/day), respectively. These results comply with the expected loads for different countries, such as Italy, Germany, Denmark (Mesdaghinia et al. 2015). Metcalf & Eddy (2013) reported PCPL for TSS and BOD for Egypt in the range of 41–68 and 27–41 (g/capita/day) respectively. The values in the current study are in the upper range of these values and are higher for BOD; this is mainly due to the low water consumption rate in the governorate, which equals 68%, compared to the country.

Treated wastewater quality

Table 3 shows the yearly average treated wastewater characteristics during the study period for each WWTP, and for the whole governorate, the monthly average values of temperature ranged between 22.71 and 26.61°C; the pH value ranged between 6.72 and 7.57, TDS ranged between 517.29 and 1162.22 mg/l, TSS ranged between 24.02 and 466 mg/l, COD ranged between 39.08 and 394.44 mg/l, BOD ranged between 29.89 and 259.89 mg/l, NO_3 ranged between 3.79 and 70.95 mg/l, O&G ranged between 6.88 and 55.06 mg/l and DO ranged between 1.32 and 5.40 mg/l. These results show the removal ratio of TDS, TSS, COD, BOD, and O&G ranged

Table 3. Yearly average treated wastewater characteristics during the study period

WWTP	Temp (°C)	pH	TDS (mg/l)	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	NO_3 (mg/l)	O&G (mg/l)	DO (mg/l)
Abu Hamad	23.59	7.35	517.29	30.43	68.00	42.71	70.95	12.73	5.20
Abu Kabir	23.58	7.33	956.09	34.00	54.73	35.73	62.01	11.11	4.13
Abu Metna	22.97	7.35	914.00	31.05	58.00	36.45	43.60	18.24	4.59
Al Halawat	25.15	7.54	907.50	58.00	105.42	67.00	22.19	17.28	2.70
Al Hussaniah	25.68	7.31	956.00	29.91	54.18	35.27	39.96	9.05	4.59
Al Qenayat	24.14	7.36	756.89	28.56	52.78	33.11	51.01	15.66	5.16
Al Qurin	24.12	7.38	726.93	53.29	60.36	39.07	33.24	14.33	4.53
Al Rewad	26.1	6.75	1094	**68.00**	**123.8**	**82.2**	13.68	19.2	**2.68**
Al Robomaiah	23.80	7.19	717.64	30.82	54.64	33.82	39.38	14.55	**3.92**
Al Taibah	24.84	7.60	915.18	47.18	89.36	57.36	23.43	22.85	**3.04**
Al Zagazig	24.87	7.28	938.90	**98.60**	**143.80**	**96.20**	10.68	22.04	**2.22**
Anshas	25.94	7.33	833.27	31.31	49.33	37.67	29.91	18.29	4.44
Awlad Saqr	22.98	7.27	854.64	30.27	51.27	33.27	29.49	7.16	4.31
Fakous	23.26	7.18	761.06	47.53	75.00	**65.18**	20.32	15.87	4.11
Heheia	25.04	7.13	760.00	**66.07**	**106.27**	**69.00**	28.10	26.49	**3.12**
Kafr Saqr	24.35	7.29	809.58	32.67	60.58	40.17	27.15	12.05	**3.72**
Lebo	24.69	7.33	977.17	40.83	78.33	49.92	22.37	17.53	**3.79**
Pordin	26.61	6.63	1010.00	**120.36**	**182.82**	**119.73**	7.99	**23.91**	**1.99**
Safor	22.71	7.14	1246.00	**146.50**	**363.00**	**239.90**	17.43	**40.30**	**1.59**
Shlshalmon	24.31	7.27	749.46	26.02	42.23	27.69	26.83	**11.42**	4.45
Sowod	24.56	7.57	1087.82	30.27	47.91	32.36	43.32	9.80	4.78
Governorate average	24.41	7.29	768.32	**70.73**	**87.59**	**58.80**	29.85	**20.57**	**3.81**
Standard	20 - 35	6.5 – 8.5	< 2000	< 50	< 80	< 60	< 50	< 10	> 4

***Bold** values do not meet the objective between 18–30%, 45–93%, 55–93%, 56–92% and 16–89% respectively, while the NO_3 concentration increased. This is due to the nitrification process and lack of denitrification (Yun et al. 2018, Nasr & Ismail 2015). These removal ratios comply with the results of Mahgoub, et al. (2015) who reported a removal ratio of BOD, COD and TSS up to 90%, 89% and 88%. Also, these results comply with those of (Metcalf & Eddy, 2013; Qaim, 2017; WEF, 1998).

Table 3 shows the Egyptian standard for secondary treatment degree in case that the final disposal of treated water will be in agricultural drainage as 25–35°C, 6.5–8.5, 2,000 mg/l, 50 mg/l, 80 mg/l, 60 mg/l, 50 mg/l, 10 mg/l and more than 4.00 mg/l for temperature, pH value, TDS, TSS, COD, BOD, NO_3, O&G and DO, respectively. All treatment plant effluents meet the standard for temp, pH and TSS values, while the percent of complying with the standard was 71th percentile TSS, COD and BOD, 81th percentile for NO_3, and 50th percentile for O&G and DO. It is obvious from the above-mentioned results that the final judgment on the performance of the WWTPs is not clear; therefore, a clear and specific method such as the WWQI is required to have such judgment.

WWQI for the tested WWTPs

WWQI for each WWTP was calculated using the whole year data, Table 4 shows the WWQI for each plant and average value for the Governorate. According to the scale shown in table 1, only 2 WWTPs give a good performance (9.52%), 9 WWTPs give a fair performance (42.86%), 9 WWTPs give a marginal performance (42.86%) and 1 WWTP is in bad condition (4.56%), the average performance all over the governorate is considered marginal.

Empirical model for predicting WWQI

Multiple linear regression (MLR) model was applied as a statistical tool for the prediction of WWQI based on the average recorded treated wastewater quality parameters shown in Table 3. Tables 5 to 7 show the output data from the analysis of variance (ANOVA) model, coefficients and statistical results from the MLR model and regression statistics of the drive model which shown in equation 9. As shown in table 7, the R square is 0.99, which indicated that 99% of the variance of the dependent variable being studied is explained by the variance of the independent variable (Ayoub & El-Morsy 2021); this is also shown clearly in Figure 2.

$$WWQI_i = -1.148\,T + 9.058\,pH + 0.009\,TDS + \\ + 0.128\,TSS - 0.063\,COD + 0.014\,BOD - \\ - 0.176\,NO_3 - 0.444\,O\&G + 7.863\,DO \quad (9)$$

CONCLUSIONS

The operation data from 21 full scale WWTPs were used in order to determine the

Table 4. WWQI for each plant during the study period

WWTP	WWQI	Level of treatment
Abu Hamad	65.34	Fair
Abu Kabir	65.90	Fair
Abu Metna	66.39	Fair
Al Halawat	52.40	Marginal
Al Hussaniah	61.00	Marginal
Al Qenayat	66.53	Fair
Al Qurin	66.24	Fair
Al Rewad	53.71	Marginal
Al Robomaiah	77.48	Fair
Al Taibah	55.47	Marginal
Al Zagazig	59.09	Marginal
Anshas	72.70	Fair
Awlad Saqr	80.65	Good
Fakous	65.27	Fair
Heheia	56.88	Marginal
Kafr Saqr	60.18	Marginal
Lebo	58.54	Marginal
Pordin	48.11	Marginal
Safor	42.11	Poor
Shlshalmon	79.57	Fair
Sowod	86.27	Good
All Governorate	63.80	Marginal

Table 5. Output data from ANOVA model

	df	SS	MS	F	Significance F
Regression	9	87136.55	9681.839	142.413	4.3481E-10
Residual	12	815.8076	67.98397		
Total	21	87952.36			

Table 6. Coefficients and statistical results of multiple linear regression model Output data

	Coefficients	Standard Error	*t* Stat	*P*-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
T	-1.148	1.698	-0.676	0.512	-4.847	2.552
pH	9.058	5.885	1.539	0.150	-3.765	21.881
TDS	0.009	0.017	0.540	0.599	-0.027	0.045
TSS	0.128	0.227	0.562	0.584	-0.368	0.624
COD	-0.063	0.377	-0.168	0.870	-0.884	0.758
BOD	0.014	0.550	0.025	0.980	-1.184	1.211
NO_3	-0.176	0.223	-0.792	0.444	-0.661	0.309
O&G	-0.444	0.572	-0.776	0.453	-1.691	0.803
DO	7.863	4.872	1.614	0.133	-2.753	18.480

Table 7. Regression statistics of the model

Regression Statistics	
Multiple R	0.995351414
R Square	0.990724437
Adjusted R Square	0.901207396
Standard Error	8.245238983
Observations	21

main wastewater pollution generation per capita per day and to assess the performance of the WWTPs in the governorate. It was found that the wastewater strength of the governorate is placed between the medium and high strength wastewater with tendency for higher values. The 90th percentile PCPL for TSS, COD, BOD, NO_3 and O&G were equal to 57.42, 91.59, 59.13, 1.64 and 12.39 (g/capita/day), respectively. All treatment plant effluents meet the standard for temp, pH and TSS values, while the percent of complying with the standard was 71th percentile TSS, COD and BOD, 81th percentile for NO_3, and 50th percentile for O&G and DO. WWQI for each WWTP was calculated and shows that 2 WWTPs give a good performance (9.52%), 9 WWTPs give a fair performance (42.86%), 9 WWTPs give a marginal performance (42.86%) and 1 WWTP is in bad condition (4.56%); the average performance all over the governorate is considered marginal. A simple model based on multiple linear regression was derived and found to be very effective in predicting the WWQI for the WWTPs.

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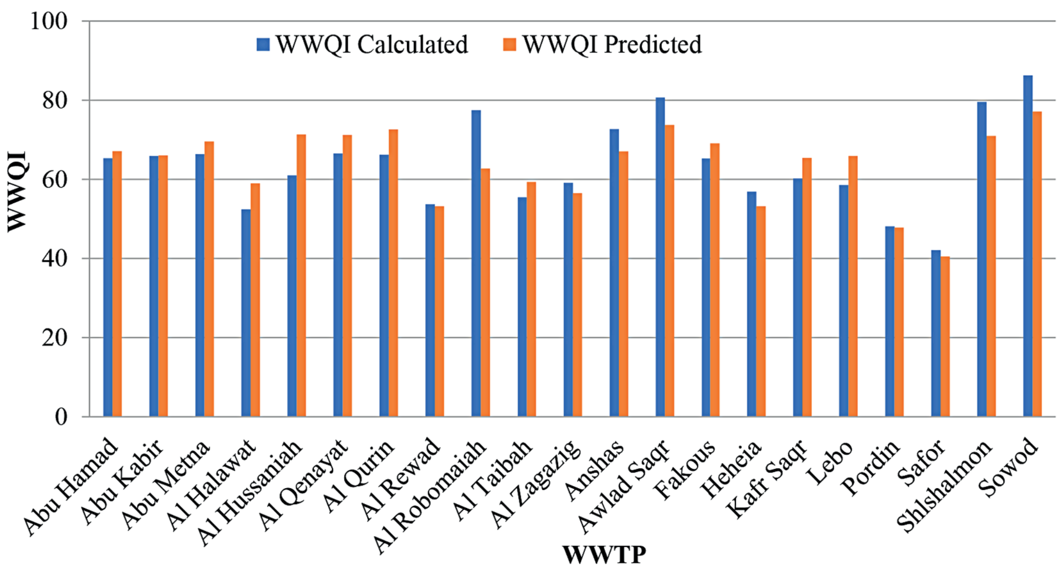

Figure 2. Estimated and predicted WWQI for WWTPs in the Sharkia governorate

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